Research-based Design Principles for the Integration of Olfaction into Young Children's Stories

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Olfactory design examines the influence of smell on user experience. Thus far, most studies have focused on the effects of odor on adults and how smell can complement commercial, marketing, and therapeutic objectives. In this paper, we focus on olfactory story design with and for children. We synthesize lessons from three empirical studies, in which we directly examined children's responses to various mechanisms for incorporating odors into early childhood story-related activities. Based on our observations and theoretically derived insights, we propose an empirically validated framework for the design of odor-enhanced children's story experiences. The framework is underpinned by the theoretical concepts of reader transactions (Rosenblatt, 1988) and environmental affordances (Gibson, 1977) and four research-derived principles: sequence, intensity, pace, and congruence of olfaction in stories. The framework also emphasizes the child's active role in the interactions. The design insights presented in this paper are intended to support designers to effectively incorporate smell into both analog resources (books), as well as digital applications (apps) and other story mediums for young children, and expand design studies with an evidence-based approach towards innovation in olfactory design.

Keywords **–** (e)book Design, Interactivity, Olfactory Enhancement, Reading, Transactional Theory.

Relevance to Design Practice **–** This work contributes research-based design insights from, and a framework for, the development of olfactory story experiences for children. These insights will support designers of books, digital applications, and other story mediums in the development of future olfactory enhanced materials for children.

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Introduction

The sense of smell (olfaction) is a historically underappreciated sense within design studies. In the past decade, however, an increasing interdisciplinary interest in sensual urban design (Henshaw et al., 2017), multisensory learning (Shams & Seitz, 2008), and sensory literacies (Rowsell, 2014), have made more researchers become attentive to the role of the sense of smell in user experiences.

Smell in Product Design

There is no doubt that smell plays a role in product design, attested to by both experimental and explorative studies. Through iterative testing in design studies, several key properties emerge as significant in published literature. First, the odor should act as a "diagnostic" for a particular product/ object by adding new and relevant information (Bone & Ellen, 1999). In addition, when odors are congruent with a memory, that congruity enhances 'accessibility' to the memory or stored information. It leads to greater elaboration when story-telling and more positive product judgments by adult consumers (Bone & Jantrania, 1992). Furthermore, surprise seems to play a role: Ludden and Schifferstein's (2009) study investigated how added scents influenced product evaluations when those smells were surprising to the users. They found that unexpected scents in products were moderately positively received by the users, influencing their perceptions of the objects. The diagnostic of the odor for the product was important for positive perception, highlighting the need for designers to align users' expectations around smell properties with the final objects.

These and other studies employing smell in design (e.g., Sharma & Estes, 2024; Lyu & Huang, 2024) highlight that odors play a significant role in users' perceptions of, and experiences with, various objects. The literature is clear that odor can be used for multi-sensory marketing, for influencing purchase decisions, consumer behavior, and product evaluation, and therefore, for driving retail behavior (Baron, 1997; Mattila & Wirtz, 2001).

Smell and Memory

The literature further suggests a clear connection between odors and memory. For example, research by Leret and Visch (2017) explored how smells, as 'sense data,' encode practices and experiences that can be retrieved later, reinforcing social

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coherence and bridging past and present. In addiction therapy, smells serve as retrieval cues to access past traumas or memories related to substance abuse, and often, different associations can be linked to a single odor molecule based on an individual's past encounters. In Leret and Visch's study, the use of a smell web and templates at a workshop showed that the coherence between individual smell molecules and personal stories elicited powerful autobiographical memories in the participants. This is important as it highlights that smell-evoked stories can elicit rich, episodic memories, which could enhance healthcare professionals' work with clinical cases of trauma. Recent research has further shown that pain intensity and unpleasantness can be influenced by olfactory cues (Sandri et al., 2021), extending the link from memory of the mind to memory of the body.

Smell and Art Projects

Beyond consumer behavior studies and clinical uses of smell for eliciting personal memories, smell has also been employed in various artistic installations. An example of artistic smell in design is Sissel Tolaas' work, which has been field-defining for smell integration with artistic installations and popular culture. Olfaction has also been highlighted as an important sense for interaction in religious settings, especially in cross-cultural studies (Majid, 2021). These studies have highlighted the idiosyncratic (unique and personalized) nature of human responses to smell stimulation, although some common responses in cultures have also been noted (see, for example, the Japanese and German comparisons in the study by Ayabe-Kanamura et al., 1998).

Smell and Digital Applications

The power of smell for consumer perceptions, eliciting memories (see Majid, 2021), and conveying political, social, and cultural messages (Classen, Howes, & Synnott, 2002), also holds significant potential for digital applications. Emerging research in odor biometrics shows that digital olfactory design has an impact on various mechanisms implicated in engagement and behavior (Spence et al., 2017). While designers are interested in the development of olfactory interfaces that deliver fragrance to consumers digitally, adding smells to entertainment activities, such as theme parks and digital entertainment environments like scent-enabled video games (Spence, 2021), has yielded varying effects. As olfactory technology becomes more mainstream and sophisticated, it is likely that the user experience will improve. For example, Carter et al. (2023) outlined recent advances in olfactory technology, which is increasingly part of mainstream environments, including classrooms. In the rapidly moving technological development landscape, it is important that researchers consider non-intrusive methodologies that capitalize on the latest technological know-how (such as the teleportation of smells, see Osmo AI Labs https://www.osmo.ai/) while, at the same time, allowing for a nuanced understanding of both positive and negative effects connected to strategic smell stimulations.

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Janine A. Campbell is an independent academic based in Wellington, New Zealand. Janine's research focuses on social phenomena impacting women in society and children in schools. During her time as an associate professor at the University of Stavanger, she worked with Natalia on a project exploring how olfaction can enrich children's reading experiences.

Smell and Studies with Children

So far, design studies with olfaction have almost exclusively involved adults. The few design studies that have focused on children have had a specific focus on children with special needs, where the smell was used as part of a multisensory stimulation to compensate for or supplement an experience (e.g., Edirisinghe et al., 2022). Given that smell-related research with typically developing children has been scarce, little knowledge exists regarding why such research matters, how to approach it methodologically, and, importantly for our work, how to best design olfaction-enhanced experiences for children.

Our Study Aims and Objectives

In this paper, we summarize the lessons learned from three studies that we conducted as part of a large-scale publicly funded research project (Research Council of Norway, Project 314117):

1. A museum exhibition that engaged children in a story with strategically placed smell boxes in an exhibition area.
2. An empirical evaluation of how families interact with smell-enhanced (scratch and sniff) books during shared book reading at home.
3. An experimental investigation of the impact on children's learning when reading a digital book (an ebook) enhanced with olfactory stimuli.

By synthesizing insights from these three distinct yet interconnected studies on smell, we propose an evidence-based design framework for effectively and meaningfully integrating smell into children's stories. With *effective*, we refer here to the use of smell that has been associated with measurable outcomes, as demonstrated by the findings from our studies (see, Kucirkova & Mwenda Chinula, 2023; Løkken, et al., 2023; Løkken, et al., 2025) and as specified by the What Worked Clearinghouse criteria (What Works Clearinghouse, 2022). With *meaningful*, we mean the incorporation of smells not for superficial allure (which is often exploited in commercial olfactory applications, see Spence, 2021), but to enrich children's experiences of stories and to empower them in the process as active participant protagonists in the design (see Iversen, Smith, & Dindler, 2017).

Throughout our work, we refer to olfactory story design rather than the design of olfaction, given that we did not design the specific fragrances but rather the overall experience for the child.

We are not trained fragrance developers, and, in the projects, we used off-the-shelf available fragrances tested as safe for children of kindergarten age, or we collaborated with International Flavors & Fragrances Inc. (IFF), an American corporation that creates fragrances based on client specifications. For the latter, we commissioned IFF to develop the scents to correspond to the desired olfactory experiences for the children and the stakeholders we worked with in the project (olfactory artists, researchers, librarians, and teachers). While we did not mix the chemicals to create the fragrances, we provided specifications regarding their intensity, hedonic quality, and other characteristics to ensure their effective use in our research and design process.

Our framework was derived from a theoretical and empirical synthesis of the findings of our studies. The procedure followed the steps of an integrative review (see Whittemore & Knafl, 2005), whereby we used multiple sources of data, both qualitative and quantitative, and combined them with theoretical sources to derive a conceptually saturated framework. We outline the procedure in three sections in this paper. In the first section, we situate the study within our theoretical rationale, providing an overview of our project's theory of change and how it relates to extant research on olfactory design. The next section delves into the three empirical studies from which we extract key design principles. Finally, the third section consolidates these principles, presenting a framework aimed at designers and design researchers interested in children's olfaction-enhanced stories.

Theory of Change

In this section, we describe the theoretical rationale for our focus on narrative storybooks and their connection to smell in the context of early childhood research. We begin with a research summary on olfactory design, followed by early childhood research on narratives and the connection between the two bodies of research. We then present the theoretical bridge between these bodies of work, drawing on Rosenblatt's and Gibson's theories.

Olfactory Design

design refers to the use of smell to enhance objects or environments, either through the addition of natural and artificial aromas or through enhancing the ambient smells in a given setting (Maggioni et al., 2020). Olfactory design doesn't need to be an expensive human-computer interaction endeavor that prohibits experimental testing. Indeed, Brooks and Lopes (2023) demonstrated the usefulness of a low-fidelity prototyping toolkit that they created for designers to assemble olfactory proofs of concept by pasting scratch-and-sniff stickers onto paper tape. Such prototypes can also be used with children, for example, with natural smells from everyday environments, like kitchen spices and herbs, extracted for smell stimulation. Such an approach can offer ideas for design and foster children's curiosity in building a relationship with natural smells (see Hopman, 2000).

Thus far, most olfactory design has been concerned with adult users. As Arlinkasari and Cushing (2018) point out, effective designing for children means being aware not only of the affordances of the specific objects but also of children's developmental stages—there is a crucial difference between designing for children and designing for adults. In our project, we therefore paid specific attention to developmental processes that are specific for children's young age and might be implicated in olfactory design. One such process is mental word stimulation in early language development.

Mental Word Stimulation Through Smell

The evidence of mental word stimulation through odor is, in comparison with visual and auditory stimulation, limited, which may be attributable to the limitations of language for describing odor in Western cultures (Speed & Majid, 2018). Asian-speaking communities (for example, Austroasiatic, Malay peninsula, and communities using the Jahai language) have many more abstract descriptive odor categories than Western cultures, and these terms are incorporated into everyday language (Burenhult & Majid, 2011). Mental word stimulation through odor may, therefore, be culturally nuanced and be able to be extended through more descriptive language. Even though studies examining the role of olfaction in education are not available, based on the current literature, we hypothesized that through an increased focus on olfaction in children's narratives, novel insights into language development might emerge. This hypothesis was part of Study 3, in which we tested olfaction-enhanced reading and children's vocabulary development.

Olfactory Entertainment

Olfactory stimulation aimed at enhancing entertainment has a notable history (The Lempert Report, 2023). In the 1960s, technologies like AromaRama, Smell-o-vision, Odorama, and Aroma-scope introduced the public to smell-enhanced movies, though these methods were plagued by issues such as noise, uneven scent distribution, and unreliability. A significant development occurred in 1981 with John Waters' film Polyester, which employed numbered scratch-and-sniff cards synchronized with on-screen cues. Since then, Disney has integrated scents into various experiences, including both themed rides and films featuring aromas, such as stink bugs in *It's Tough to Be a Bug* (1998) and sweet, outdoorsy, and ginger sushi scents in *Monsters, Inc.* (2006).

In 2012, Harvard researchers, in collaboration with Le Laboratoire in Paris, introduced a suite of olfactory apps and devices, including oSnap, oPhone, and oNotes, which allowed users to send smells along with images via MMS (Stinson, 2014). These devices, which were used to transmit both expected and emotive scents, such as the smell of chocolate with a picture of hot chocolate or with a new boyfriend, demonstrated the possibilities of diverse applications of scent in digital communication (Rawson & Field, 2022).

Currently, media experiences can be enhanced through devices like AromaPlayer, which synchronizes scent with video using a wearable device called AromaShooter, available from the Japanese company AromaJoin. Another recent development is a

small, wireless olfactory device that can be worn under a face mask (Liu et al., 2023). Discussions are ongoing about integrating olfactory generators into virtual reality (VR) to address the neglect of smell in modern VR environments (Smith, 2023), while the rise of generative AI in 2023 has sparked renewed interest in advancing sensory technologies beyond vision and hearing to include taste and smell. Nevertheless, this commercial and academic interest has been exclusively focused on adult populations.

Benefits of Olfactory Design for Children

When exploring the uncharted waters of digital olfactory design for children, we were inspired by literature from various disciplines, including psychology, consumer research, and cognitive sciences, that provided insights into the potential of olfaction for various aspects of children's experiences. For example, in the field of olfactory cognition, which employs experimental and brain imaging methods, olfaction was shown to be related to long-term memory (Delaunay-El Allam et al., 2010) and attention (Zucco et al., 2014). These insights motivated our interest in learning benefits related to memory, such as story recall, when examining children's responses to digital olfactory books. Psychology experiments show that olfactory stimulation activates more brain activity than visual stimulation (Arshamian, et al., 2013), which indicates the potential role of smell in language-related outcomes such as literacy. These potential pathways can be explored through several activities, but in our project, we focused on narrative book reading, also known as shared book reading (SBR). SBR is considered the literacy activity 'per excellence' in early childhood (Sénéchal, 2017) and was therefore central to our studies.

Narratives and Storybooks

A narrative is a "text that brings a story to mind" (Ryan, 2017, p. 521). Central to narratives are a storyline trajectory (story plot), story characters, and an underlying ethical or moral message. By adopting the term "storybooks" for narratives in book form, we align ourselves with literature that revolves around fictional narratives presented in book form. For children, such narratives have also been described as picture books, although some scholars refer to picture books exclusively to describe artifacts of exceptional literary and aesthetic attributes (see Nikolajeva & Scott, 2013). Given our project's multidisciplinary focus with multiple stakeholders, each bringing their own definition of what quality storybooks for children might mean, we adopted the term storybooks to neither exclusively emphasize didacticism nor claim that the children's narratives used in our studies attained the highest literary quality.

Storybooks can be available in both print (analog) and digital (e-book) formats, and in our project, we used both formats, responding to the research that shows that digital books play an increasingly important role in children's learning (Troseth & Strouse, 2017). However, the literature on the role of smell in print books is quite limited, with only a few recent reviews on scratch-and-sniff books for children (Spence et al., 2024). In the context of digital books, the research is even scarcer, primarily comprising non-peer-reviewed papers that address design aspects but largely neglect multisensory stimulation beyond visual and auditory elements. Therefore, our project is exploratory and combines innovative development with empirical research.

Storybooks can be of fictional or non-fictional content: fiction storybooks are crafted by authors to communicate with readers on a socio-emotional level. For young children, they serve the dual purpose of art and learning (Nikolajeva, 2013). Non-fiction books are rarely narrative as they predominantly focus on conveying facts and information to children. In our project, fictional narratives better fit our focus on olfactory design as a mechanism to stimulate diverse learning outcomes and playful experiences for children.

Studies with traditional children's stories (with typically developing children reading books at home) have found that greater story recall occurs when stories are presented in a multimedia format that combines images and texts (Verhallen et al., 2006) and when there is a congruence between the story plot and the interactive features embedded in the story (Furenes et al., 2021). We hypothesized that these principles could be extrapolated to the incorporation of olfactory stimulation into children's fictional narratives, and we have followed them in our theory of change for the project.

Another strand of literature using neuroimaging techniques has shown that passive reading of odor-related words (such as 'garlic' or 'cinnamon') activates the semantic networks for olfactory processing (González, et al., 2006) but limited work has been conducted to explore the connection with sensing odors and language processing. Nevertheless, Bordegoni et al. (2017) have made a strong case for the added value of odors in reading, proposing that the introduction of odors could improve both the immediate reading experience and the associated learning, making experiences more immersive. We included these insights into our theory of change when conceptualizing the project protocol. While all the components summarized in this short literature exposé informed our design process, the principal tenets of our theory of change draw on the theoretical concepts of affordance and readers' transactions. These theoretical concepts are explained next.

Theoretical Basis of Our Project

Two theoretical prongs have informed our project. First, the aspects of design and how children respond to olfactory stimulation were guided by Gibson's (1977) affordance theory. Put simply, an affordance is the property of an object or environment that provides users with opportunities for action. According to Gibson's theory, there is a relationship between the affordances of an object/environment and the user's capabilities to respond to those affordances. The role of designers, then, is to design objects and environments in alignment with these relationships. Gibson's concept of affordances helps explain concepts such as users' active and interactive engagement with the environment and how the environment is perceived. As Jenkins (2008) puts it: "Despite its apparent complexity, the language of affordances is simply an operationalized presentation of ethology's fundamental principle:

reciprocity between an organism and its environment" (p. 34). We incorporate this notion of reciprocity and understanding of objects' affordances when interpreting the findings from our empirical studies that involved children's interactions with original smell designs.

The second theoretical prong of our work is Rosenblatt's transactional theory (Rosenblatt, 1969, 1981, 1986, 1988), which is an influential socio-cultural theory in children's literary studies. The theory has laid the foundations for understanding texts as a dynamic resource that readers "transact" meaning with, engaging in what Rosenblatt (1988) described as efferent and aesthetic thinking. In her writings and lectures, Rosenblatt explained reading as an active meaning-making process between reader(s) and text(s), and proposed that the reader's life, past and present, and their 'physical condition' and 'particular mood of the moment' shaped and influenced their affective engagement in reading. The transactional reading theory emphasizes that reading crosses human-machine boundaries and expands the repertoire of reading media to a multisensory experience. As such, the theory directly connects to our perspective of olfaction, which is approached not merely as an object of curiosity but as a holistic and integrated experience: children transact meanings with texts, and olfaction can enhance these transactions but not replace them.

Bringing together Gibson's affordance theory and Rosenblatt's transaction theory in the context of children's reading suggests a rich, multi-sensory interaction. According to Gibson, environments offer affordances—possibilities for action—that users can perceive and act upon. When readers engage with physical texts, they transact meanings with texts that possess sensorial affordances, such as smell, visual properties, and tactile feedback. Unlike taste, which is specific to foods and not typically associated with books, these other sensory properties are integral to the environmental affordances that readers interact with. Rosenblatt's theory emphasizes that meaning is co-created through the dynamic interaction between the reader and the text. Therefore, these environmental and textual affordances are perceived and acted upon uniquely by different readers, shaped by their personal histories, current physical conditions, and moods.

Figure 1 illustrates the relationships between Gibson's and Rosenblatt's core theoretical concepts, as per our understanding of their importance for olfaction-enhanced reading with young children. In particular, the Figure shows the 'transactions,' i.e. points of connection between readers and texts through action and perception (see interconnected ovals in the middle of the Figure) and the sensorial "affordances" of reading, which relate to both the environment and the reading material (see the icons in the right corner of the Figure). The transactions and affordances intersect through readers' meaning-making, which is both a linguistic process of reading and a sensorial experience.

This theoretical understanding has several implications for how we approach olfactory design. First, it positions olfaction as a unique affordance that connects both to the ambient environment and can be deliberately added or intensified within a text. Like the affordance of sound, olfaction offers a multi-layered sensory experience. It is perceived and acted upon differently by readers, with each reader bringing their own background and context to the transaction of meaning. This dual nature of olfaction, as both an environmental and a text-based affordance, has the potential to enrich the reading experience, allowing for a more immersive and personalized engagement with the narrative.

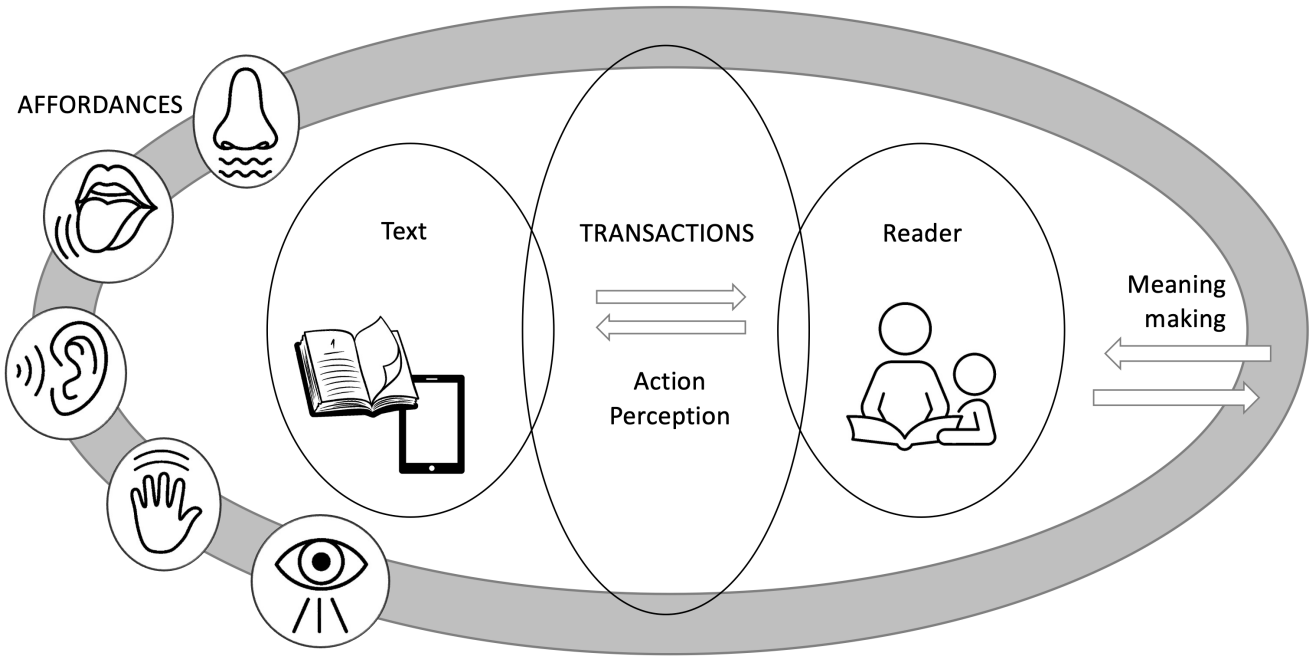

Figure 1. Key relationships between the core theoretical concepts in our theory of change.

Second, when designers approach olfaction within the context of stories, they may position olfaction as superior to stories [e.g., begin the design process by focusing on the smell properties and then adding these to an existing story; see Brooks et al. (2023) critique of this approach]. Our theoretical perspective positions olfaction as the driving force, allowing the narrative to assume various forms — digital or print — synergistically intertwined with other sensory modalities, such as visual imagery or oral narration. This approach aligns with previous research. For example, Brooks and Lopes (2023) demonstrated that low-cost prototyping with scratch-and-sniff stickers enables accessible olfactory design without requiring complex equipment, making smell an easy-to-integrate resource for enhancing user engagement. Similarly, Leret and Visch (2017) showed how smells, as "sense data," can encode experiences and trigger autobiographical memories without analyzing molecular combinations. These studies underscore that olfaction can shape interactions and experiences in design without necessitating the creation of new scents.

In sum, our theory of change is that the sensory affordances of texts enhance meaning-making interactions between the text and the reader, the reader and the environment, and among readers sharing the text. This dynamic interaction ultimately leads to greater meaning-making with the affordances of the readers' wider environment, physical and social, mediated by humans and technologies.

Empirical Insights on Olfaction-enhanced Stories

For this conceptual paper, we reviewed and summarized the design procedures and limitations from three studies of our project. We derived lessons learned and guiding principles from each of the studies. We explored how these insights connected as a framework for the development of olfaction-enhanced stories for young children.

Ethical Permissions

In each study, we followed the ethical guidance from the Norwegian authority, which is the official ethical body in our country. We obtained separate ethical approvals for each study within the project, adhering to the guidance provided by the reviewers at the Ethical Body [Norwegian Agency for Shared Services in Education and Research (SiKT)]. Each application included detailed information about the study protocol, exact procedures, and how ethical considerations—particularly those related to interactions with vulnerable populations—would be addressed.

The guidance from SiKT relies on the best international practices in ethical research with children. In particular, and in alignment with the guidance, our ethical stance regarding children's ongoing consent followed the premise put forth by Mortari and Harcourt (2012, p. 238):

> The creation of a welcoming and authentic setting for the research enterprise, first of all, obligates the researcher to give value to this act by assuming the responsibility to monitor, in each relational moment, the verification that the children are at ease in the inquiry action and that they are freely giving their consent.

Three Empirical Studies

In the sections that follow, we briefly describe each of the three studies and identify the design features, limiting factors, lessons learned, and principles that we gleaned from each. We then bring these examples together into a framework for the design of olfactory stories for young children. By describing the design intentions, successes, and challenges of three of the studies, we seek to expand the usefulness of our project to include the designers of children's resources and thus implement empirical ideas into actual resources for children's everyday use.

The individual studies were conceptualized to actively involve children and their parents, teachers, and designers in examining the intersection of technology and the natural experience of sensory engagement with stories. While Studies 1 and 2 were qualitative observational studies, in Study 3, the effectiveness of multi-sensory reading, with a specific focus on olfaction as a key sensory stimulation, was examined in relation to children's increased reading engagement, story comprehension, and learning of story-related vocabulary. The smell mechanisms varied: in Study 2, we implemented the use of scratch and sniff books; in Study 1, we developed our own 'smell boxes.' In Study 3, we used a digital storybook with accompanying smell canisters.

Study 1: Story Exhibition

In Study 1, the project team collaborated with the local museum to conceptualize, design, and run an exhibition based on an olfaction-enhanced story. The story was an adapted version of the Three Little Pigs fairy tale about three little pigs that build three houses of various materials to defeat the big bad wolf. The exhibition was designed as an interactive trail depicting the journey from one of the story characters, Mother Pig, to various stations that contained olfactory stimulation. The exhibition was intended for children, and most children visited on their own, with their parents or teachers waiting outside the exhibition. If adults accompanied the children, they could read aloud or play the voice recording of the story. However, they needed to adapt to the child-sized exhibition materials, such as the houses of the pigs, which were designed to match the height of typical kindergarten children.

The story was available as text on posters hung around the adventure trail and an audio recording that could be activated by an adult scanning the QR code on the story posters. Other than that, children were invited to explore the story in any way or sequence they liked. Most children started the trail in the middle and experienced the story without the audio-recorded narrative, but they could hear the wolf's whines in the background as these were played on repeat from the loudspeakers. Children explored the exhibition with their whole bodies in that they could freely roam around the adventure trail and engage with the artifacts and the specially created small pigs' houses.

In the exhibition, we used five smells that were matched with color and hedonic quality (positive, negative, neutral) with the story characters: for example, brown for chocolate/cocoa and the positive association with safety and home or black color for the smell box representing the wolf with an aroma reminiscent

of a wet dog's fur. The five smells were included in five wooden boxes and strategically placed around the adventure trail in the exhibition area. Each box could be easily opened and closed by the child using the wooden lid, thus allowing for easy calibration of smell intensity by each child. Also, each smell could be topped up by the exhibition curators if the visitors left boxes open and the smell's intensity decreased.

We gained two design insights during the development and implementation of the exhibition, and both related to the hedonic quality of the odors, i.e., whether the odors were perceived by the child visitors as positive, negative, or neutral. Namely, in our analysis of children's responses to the five smell boxes (Kucirkova & Gausel, 2023), we conclude that it is crucial to maintain the alignment of color and smell to ensure that children connect positive colors with positive odors. Otherwise, a mismatch can occur, leading children to associate dark colors with unpleasant smells and light colors with positive smells. This was evident during the exhibition when children perceived the positive scent of cocoa as unpleasant due to the brown color of the box, which was similar to other dark boxes symbolizing unpleasant smells (Kucirkova, 2023; Kucirkova & Gausel, 2023).

Another insight related to the odors' hedonic quality and children's responses relates to the sequence of individual odors in a story experience. While the adventure trail was designed to depict the narrative from beginning to end, not all children followed this narrative sequence. Their engagement with individual stations was heavily influenced by the guidance provided by accompanying adults, including teachers and family caregivers, who visited the exhibition with them. Those directed by caregivers to interact with the story elements tended to progress from stations 1 to 5. In contrast, children left to explore independently often began with middle stations or randomly approached the various houses representing the piglets' homes. This variance appeared to impact children's overall perception of smell pleasantness, as confirmed in our interviews with the children at the end of the research week (Kucirkova, 2023). Namely, most children commented on bad smells during the exhibition and related this bad smell to the first smell box placed inside the pig pen of the mother pig. Children who began the trail with the unpleasant odor seemed to perceive all smells in the exhibition as unpleasant, anticipating the farm smell of the pig pen. In addition, when the children visited the exhibition in kindergarten groups, one child described a box as having a bad odor influenced peers to assume the same, fostering contagious reactions.

This seemingly small design issue had a significant effect on the study's results, interfering with any inferences we could make about the psychological effects of smells. Nevertheless, the pattern aligns with research on olfactory priming- a phenomenon adapted from the social sciences, where background stimuli affect human behavior, even if the individual is not consciously aware of the stimuli. Smeets and Dijksterhuis (2014) argue that given the inherent predisposition of individuals to allocate greater attention to visual rather than olfactory attributes within their environment, olfactory stimuli often reside beyond conscious awareness when evaluating new surroundings, and it is crucial to distinguish between semantic and olfactory priming. Semantic priming refers to priming through words or categories, while olfactory priming refers to priming through odors only. Smeets and Dijksterhuis hypothesize, and our findings confirm, that odors can function as semantic primes when combined with cues from other modalities. In our case, the visual cue in the form of the smell box's lid color (dark), combined with the actual bad smell from the first box in the exhibition and the group effect of children shouting "bad smell," created a powerful priming effect for the child visitors. As the children linked the bad odor to the emotional experience of laughing and nudging each other about the bad smell, it led to encoding the experience as a memory, which, according to Smeets and Dijksterhuis, increases the likelihood that the odor acted as a semantic prime in subsequent encounters (children's further interactions with other smell boxes at the exhibition).

From our findings and literature, we conclude that future olfactory exhibitions should follow a deliberate sequence for the included odors and start with pleasant smells first. An effective olfactory design that includes several olfactory prompts should commence with mild, pleasant aromas to engage children without overwhelming them, thereby fostering curiosity and enhancing interest in exploration. While unpleasant odors can be included in a story experience for children, it is important that they do not overpower the rest of the experience and that they do not prime children to perceive other odors as similarly unpleasant. In olfactory trails and the design of story experiences that have a clear start and finish, we recommend using bad smells in very low intensities and towards the end of the sequence.

Study 2: Empirical Evaluation of Reading Scratch and Sniff Books

As outlined in our theory of change, olfaction can serve as both an environmental affordance, shaping the sensory atmosphere, and a text-based affordance, enhancing narrative engagement through smell-related descriptions. In contrast to Study 1, olfaction as text-based affordance was explored in Study 2 of the project. This entailed embedding smell directly into the storybooks and creating objects with enhanced affordances for smell, providing an olfactory experience for readers as they interact with the texts (reported in Kucirkova & Bruheim Jensen, 2023a, 2023b).

The sensory affordances in this study were different in that children were sitting closely with their parents, either on their lap or next to them, while sharing and engaging with the smells during a shared-book reading session with scratch-and-sniff books. The readings took place during the children's bedtime reading routines at home, creating a cozy and intimate environment for sensory interaction. Instead of the public exhibition space, the intimate reading atmosphere during shared book reading allowed us to employ deep qualitative analyses of the verbal and behavioral interactions of each child and thus to get insights into the patterns of bonding and verbal stimulation occurring in such family scenarios.

The study followed ten Norwegian families and their three to five-year-old children as they read together an olfactory book (the scratch and sniff book titled "Peter Follows His Nose" written

by Beatrix Potter). The methodology drew from qualitative methods influenced by socio-semiotic conceptualizations (Kress & van Leeuwen, 2002), which allowed us to critically assess the function of smell as a means of communication in SBR (Kucirkova & Bruheim Jensen, 2023a, 2023b). The analysis of parent-child behaviors showed that the odors in the books primarily served three linguistic metafunctions: the interpersonal function, which indicates personal interests; the textual function, which establishes a space for dialogue; and the ideational function, which uncovers differing interpretations. The analysis of adult-child verbal and behavioral exchanges around the books showed that the presence of the odors stimulated joint laughter, discussion episodes around memories and extra-textual references, as well as dynamic movements around the book with the use of fingers, head, and movement to get to the right intensity of the smell.

These observed metafunctions of smell correspond to socio-semiotic conceptualizations (Kress & van Leeuwen, 2002) and thus suggest that odors embedded in scratch and sniff books can be viewed as a semiotic mode within SBR. In other words, smell can be, in this respect, viewed as affording new means of communication, analogous to color, possessing a distinctive structure and distinct communication attributes.

Extrapolating from these insights for the design of other olfactory story experiences, we analyzed the design features of scratch-and-sniff books to understand better what aspects of their design allow odors to take on a prominent communicative function. One key element that emerged through our theoretical analysis, led by Gibson's and Rosenblatt's tenets, was olfactory pacing. The scratch-and-sniff book featured one scent per page, accompanied by passages of text and images. This spacing seemed to be optimal for our participants to have sufficient time for dialogue. Each smell was experienced differently by the participants, and the time it took to scratch, read the passage and proceed to the next page allowed for diverse interpretations to unfold, providing opportunities for adults and children to exchange meanings and engage in discussions. We propose that the reader-smell interaction and transaction of meaning were facilitated because there was sufficient spacing between each olfactory stimulation, guided by the design of the scratch-and-sniff book. Furthermore, as readers engage with the smells at different paces and transact meanings, the pace of processing is linked to the intensity of odors: stronger scents evoke more prolonged emotional reactions, contrasting with less intense smells that prompt a neutral emotional response.

Pace, intervals and intensity are well-known techniques in interactive storytelling, where they are used to stimulate emotional responses by viewers or readers (Hernandez et al., 2015). Incorporating smell into interactive stories broadens the factors influencing the timing and intensity of story events on a screen or page and their engagement with the viewer or reader. Striking a careful balance between these elements—pace and intensity—necessitates an understanding of how stories and narratives shape viewers' perceptions of reality and fiction (Gingrich, 2021). In the case of fictional stories enhanced with real smells, we propose that the pacing is an important design consideration to allow for children's meaning transactions without a sensory overload.

Study 3: Experimental Investigation of eBook Enhanced with Olfactory Stimuli

Study 3 offered further design insights due to several distinct characteristics: the study was set up for olfactory stimulation with a different group of participants, who engaged in kindergartens rather than at home, and due to the books' presentation in a digital format, not as scratch and sniff. Additionally, this study was rooted in a quantitative, psychology-informed approach, with an experimental approach to examine the effect of olfactory stimulation on young children's reading outcomes.

The study involved 67 Norwegian children aged 5 to 6 years. The children participated in shared book reading sessions with the researcher, who visited their kindergartens with a story written by a professional author and presented on an iPad. Alongside the digital book, the iPad experience was enhanced with olfactory stimuli delivered through five small smell canisters. These canisters, which were sourced from a children's board game designed for safe use, contained various child-friendly scents. The canisters were placed in front of an iPad and were introduced to the children at specific points in the story as prompted by the researcher. This experimental setup resulted from several rounds of trial and testing.

Namely, when developing the smell-releasing mechanism for this experiment, we systematically reviewed current commercially available mechanisms to activate odors in children. The review revealed that only a small minority of children's popular books (current titles) include scratch and sniff books [87 titles in the global Amazon children's booklist (Kucirkova, 2022)] and a systematic review of all scratch and sniff books since the first publication in 1970 (Spence et al., 2024) identified a total of 245 books (many now out of print).

We also considered digital olfactory books, such as e-books accessed on smartphones/tablets that have multimedia (e.g., sounds), simple interactive features (e.g., character movement), and the possibility to emit scents through physical extensions (e.g., Bluetooth-connected scratch cards or odor-emitting devices). However, apart from a few online references mentioning digital olfactory books as a possibility, digital olfactory books have not been studied or further developed, so they could not be employed in our study.

The hypothesis for this experiment was aligned with the overall project's theory of change, namely that olfactory-enhanced reading of stories increases children's engagement. Through this engagement, children's vocabulary learning, story recall, and overall interest in reading and smell were also predicted to increase. This theory of change was only partially borne out by the results: we found children's increased engagement in stories that were stimulated by the smell, but this engagement did not translate into the learning outcomes of vocabulary learning or story recall (Løkken et al., 2025).

Reflecting on the discrepancies between the anticipated design and the final experimental artifact, we consider the key barrier to the intended design of the research artifact to be technological in nature: We initially envisaged a digital device connected to an iPad, releasing olfactory stimuli at relevant points

of the story (with simple manipulation appropriate for children to use unaided). This design was based on our knowledge of advances in aroma release, detailed earlier in this paper. However, this technology was found to be less well-developed than anticipated and not accessible for our study due to technological, economic, and child usability limitations. Therefore, in its final implementation, we used a standing iPad containing the story with smell stimuli moments marked in the text alongside smell canisters for each instance of olfactory stimulation. This meant that the smell was not fully integrated with the reading experience, as children had to engage with the canisters and book pages as separate media. We hypothesize that this segmented interaction disrupted the experience and interrupted the anticipated flow of effects, where olfaction could act as a stimulus to enhance children's story comprehension and learning.

Further design limitations that we encountered were also linked to the type of smell stimulation available for the study: namely, the need for the development of equally potent, durable scents, mostly pleasant with one musty/earthy smell, that could be effectively isolated from each other and not cross contaminate the smell instances in the story. That said, our final, much-simplified design enabled us to ensure that smells were isolated one from another, that children had adequate time between smells to cleanse their nasal palate, and that the musty/earthy smell (least pleasant smell) was not overpowering the story by either its placement or intensity and that the experiment could be conducted with a smell release technology that was easily and safely manipulated by the children themselves. As such, the design of the olfactory story experience for children in this experiment capitalized on the lessons learned throughout the project and offered a workable, although not ideal, solution for running the experiment according to the required methodological parameters.

Reflecting on the design considerations and study results, additional insights emerged for effectively incorporating olfactory stimuli into the children's story experience. Specifically, when applying Gibson's affordances theory and Rosenblatt's transactions, we noticed that the selection of odors for story plots and characters must align not only with hedonic qualities but also with the unfolding events in the story plot. Story plots typically encompass various events, featuring dramatic and culminating moments within the traditional narrative arc. Study 3 demonstrated that odors presented to children during a story experience need to align with the unfolding events in the narrative, i.e., that they are congruent, in order to facilitate children's comprehension of the narrative, aid in memory consolidation, and enhance their later recall of the story.

The design concept of congruence draws upon insights from both theoretical design research and empirical literacy studies. In particular, Klaus Krippendorff's (1995) thesis that "the systematic exploration of how artifacts arise, make sense and meaning in their user's understanding" (p. 5) is key to designing objects and artifacts that users can make sense of within their own context and sphere of living. For this, the objects need to be designed "in tune with 'what' we face, touch, hear or handle when we directly and unreflectingly understand how 'something' is situated in the context of our living" (p. 5). Objects that make sense are objects that are aligned with users' sensorial engagement (Krippendorff, 2018). While smell was not central to Krippendorff's theory of semantics, there are some parallels here with how the research on smell congruence explains our findings of children's interaction with the smell canisters in the experiment.

Furthermore, it has been empirically established that the intensity and pleasantness of odors and tastes are influenced by their congruence/alignment (see Krishna et al., 2010): tastes and smells are combined with an associated meaning, and if there is a perceptual match, the intensity of smells and odors is higher (Amsellem & Ohla, 2016). In addition, multiple literacy studies involving young children have demonstrated that congruent story events and interactive features, particularly in digital books, more effectively support children's recall compared to incongruent elements (Furenes et al., 2021; Shapiro & Hudson, 1991).

Taking the research and our empirical insights together, we derive that when there is congruency in the pairing of smell with specific resources, changes in behaviors can be observed. This proposition aligns with the findings of Bone and Jantrania (1992), who provide evidence indicating that congruence between specific odors and products (e.g., lemon scent with household cleanser) results in more favorable product assessments compared to incongruent pairings (e.g., coconut scent with household cleanser). Hence, it is conceivable that aligning smells with specific story events, such as introducing a dramatic scent during a climactic story ending, could elicit a stronger and more favorable response from the reader towards the book. However, due to the highly individualized nature of olfactory responses, determining the precise intensities and types of smells perceived as congruent or incongruent for various story events poses challenges. As a recommendation, we suggest applying the principle of congruence as a general guideline and advocate for its validation in specific applications based on the outcomes of testing and pre-testing within each specific context of use.

In addition, given the pragmatic difficulty of designing natural smells effectively, we recommend linking smell moments to story enhancement with ambient smells rather than developing artificial smells that may be congruent but are perceived as disturbing due to their artificial character. For instance, instead of the smell of chocolate, when the story mentions hot chocolate (as the child may focus on whether the odor precisely resembles chocolate), it is preferable to introduce a warm, sweet, ambient smell.

Such atmosphere-based congruency aligns with the redundancy principle discussed in research on reading and multimedia (see Mayer & Moreno, 2003), which suggests that information should be presented only in one modality for reader's meaningful interaction: high-quality picture books are those that do not repeat the same information in images and texts but rather use both modalities to expand on the information (Nikolajeva, 2013). Similarly, when it comes to olfaction, it should be used to enrich the information already provided in any other modalities. Hence, when readers receive information about a story event in the book through text or images (visually), the congruent olfactory cue should not repeat this information but align with it with an ambient adjustment of the olfactory environment around the child.

Design Principles

The empirical lessons adopted from the three studies lead us to four main design principles, which we elaborate in this section, with attention to our theory of change.

Sequence, Intensity, Pacing, and Congruence

Our three studies on children's interactions with scratch-and-sniff books, smell boxes in an exhibition, and smell canisters while reading a book on an iPad demonstrate how the physicality of objects and spatial environments influences action and movement. According to Gibson's (1979) theory, these possibilities are shaped by the "affordances" of objects and environmental features, which both constrain and enable activities. For children to be successful agents in the physical world, therefore, hinges on their ability to perceive and exploit these affordances.

As demonstrated in the story exhibition, the smell moments within a child's story must be ordered intentionally and with a purpose to ensure the desired effect. Our observation data showed that starting with unpleasant smells meant that children became primed to unpleasant smells and refused to engage with follow-up smells or failed to perceive them in their true quality. We therefore recommend starting with pleasant or neutral smells, including unpleasant smells during the middle of the story, and finishing with a pleasant or neutral smell.

Rosenblatt (1969) emphasized that sequencing in fiction, poems, and other texts is a technique that elicits different responses from readers and is vital for meaning. She used examples of poems where a reader cannot fully understand the meaning until both the first and last lines are read and interrelated. Her examples showed a kind of back-and-forth in meaning exchange between readers and authors, as understanding comes together only when texts are read in the correct sequence. The same principle applies to smells; they cannot be randomly added to a narrative but require a well-thought-out strategy for inclusion in a narrative.

Related to sequencing is the intensity of smells. For a coherent experience of the story, it is important to ensure that all smells have the same intensity. When the intensities are different, children will focus only on the stronger of the smells and are unlikely to recall smelling anything else. Furthermore, for any smells included in a story, adequate time between olfactory stimuli must exist. So that released smells can dissipate and the nasal palate can be cleansed, it is crucial to introduce some time gaps between the olfactory stimuli. If smell instances come too closely together, they will fail to enhance the story or promote engagement in narrative moments. Instead, designers can introduce longer reading breaks or story passages to allow for both the story and olfactory stimulus to be processed by children.

Rosenblatt (1986) emphasized that as readers 'transact' meaning with texts, they exchange not only learning or cognitive meanings but also emotional and aesthetic experiences. The latter is particularly relevant for fictional stories and the principle of congruence. As highlighted in Study 3, a narrative possesses an aesthetic value that can be enhanced by odors aligned with this value. These odors should not merely replicate the aesthetic value but rather introduce another dimension, avoiding a direct translation of semantic meaning into smell. Instead, they should be introduced at the appropriate time of the event, featuring aligned hedonic qualities and serving to augment the story event as an ambient smell for the environment or atmosphere. Repeating the information provided in the text with a matched smell cue seems inappropriate for the aesthetic and emotional experience advocated by Rosenblatt.

In addition to these design principles, we gained additional insight during our studies, which is not exclusive to olfactory stories but pertains to design with children more broadly. We include it here for comprehensive consideration by designers: the principle of interactivity.

Interactivity

In Gibson's (1979) interactionist account, the physical attributes of objects are key affordances. However, as Norman (1999) later expanded, interaction with digital devices introduces new interactions as the physical aspect of the system (such as a computer or mouse) is further enhanced with the affordances of the software design. When it comes to interactivity in children's stories, several forms are possible; for example, with printed books, interactivity manifests through manipulative features like flaps, levers, and varied textures, while with digital books, interactivity involves digital hotspots that are activated through the child's touch, typically by tapping or swiping a designated area. Such interactive features urge readers to physically engage with the story and are thus perceived as a way to actively involve children in the story experience. Children's active involvement (rather than passive absorption of a story) is a key tenet of Rosenblatt's transaction theory, emphasizing children's voice and agency during reading in order to develop reading and writing skills, and also the aesthetic appreciation of texts (Rosenblatt, 1981). Appropriate technology, able to be manipulated by children and capable of automatically releasing odors at certain points in a story, has yet to be developed. However, even the simple manipulation of smell canisters, as undertaken in Study 3, was an interactive way to engage children's direct participation in the reading session.

Therefore, we recommend that children's interaction with the olfactory story mechanisms, whether they are smell canisters, scratch, and sniff surfaces, or larger smell boxes placed in the space, is another principle for designers looking to develop effective story experiences for children.

Framework for Designing Children's Olfactory Story Experiences

Our proposed framework brings together the principles from both Rosenblatt's and Gibson's theories and the empirical insights from our project. The framework describes how the principles can be extrapolated to the future design of children's olfactory narratives. The framework begins by emphasizing the theory of change, asserting that reading serves a purpose beyond engaging readers,

aiming to impact their learning, comprehension, intrinsic interest in encountering more texts, and, in our case, heightened interest in stories and smell. From this standpoint, smells that are congruent with the text are more supportive of the mechanisms in the theory of change, as they facilitate the connection between smell and the story. Furthermore, the order of smells (starting with neutral or pleasant smells) is crucial for positive outcomes and to ensure the complete cycle of olfactory experience in the story is followed.

The framework loop also highlights the balanced intensity of smells (maintained at the same level for each smell), along with the timing of smell delivery, which involves providing adequate time between odor exposures to cleanse the olfactory palate. The subsequent loop in the framework aims to ensure that smells enhance the story without duplicating information already conveyed through other modalities. This is more attainable with smells representing ambient and abstract scents rather than specific odors, especially if the design prioritizes natural over artificial smells.

Finally, to keep the child engaged throughout the process and derive long-term benefits for their reading motivation and interest in smell, it is essential that the smell mechanisms can be directly handled by the children, giving them agency to "transact" meanings through and with diverse texts.

In the description and depiction of the framework (see Figure 2), we focus on the specific context of reading and the book format of narratives. However, the framework can also be used for oral narratives (storytelling), or as shown in Study 1 during children's movement across the exhibition space, and also for embodied experiences of narratives.

Conclusion

The key lessons learned from our project for the design of children's olfactory stories bring a much-needed and nuanced approach to the under-researched contribution of the sense of smell to children's design. This article, focusing specifically on design insights from our Norwegian project, aimed to support designers of books, digital applications, and other story mediums for young children with evidence-based principles for optimal olfactory-enhanced stories.

For the effective and positive impact of olfaction on children's story experiences, the design should present odors that are equally intense, adequately sequenced across pleasant and less pleasant smells, and paced to allow cleansing between various types of smells. In addition, the odors need to be congruent with the story events and presented in a complementary and coherent manner with the story, ensuring an ambient story experience for the child. When combined with a form of interactivity that is appropriate for young children, children's experiences of stories will be enriched. In such encounters with olfactory stories, the reader can appropriately respond to what Rosenblatt fittingly described as aesthetic meanings called forth in the transaction with narratives.

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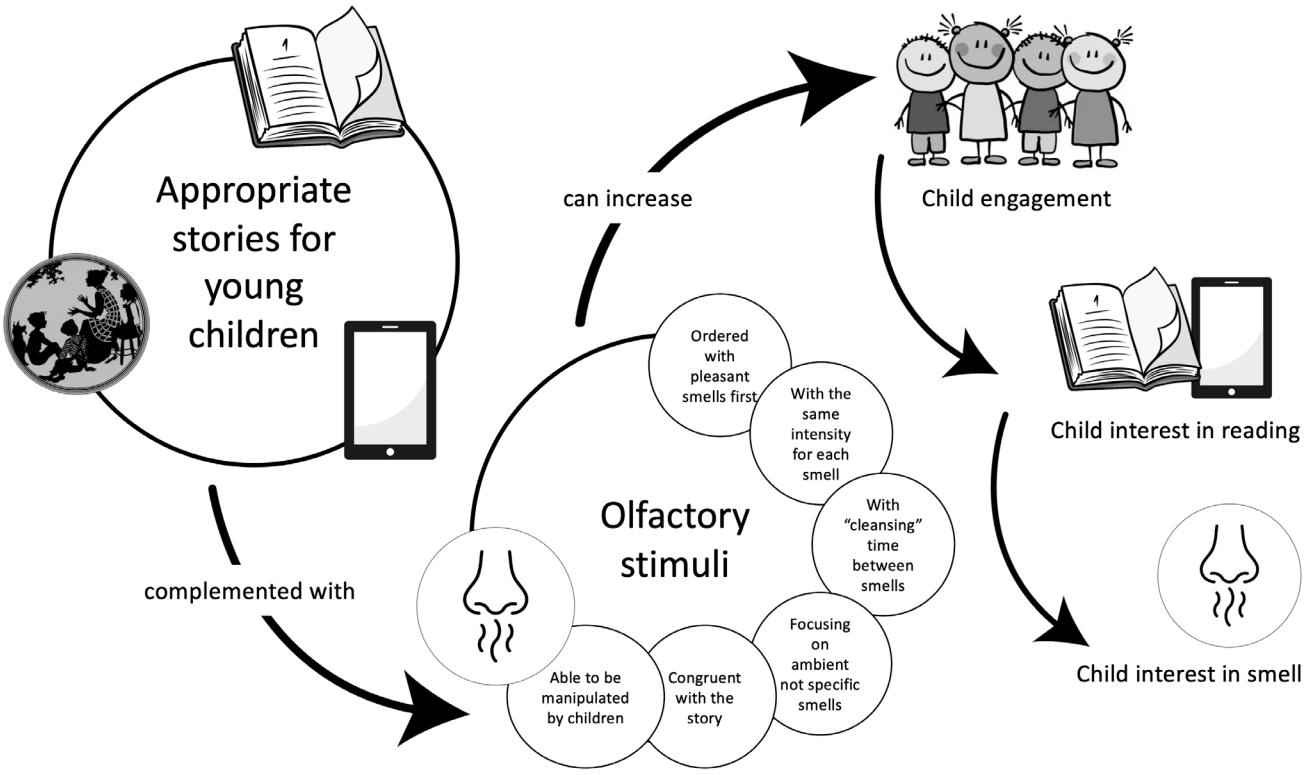

Figure 2. Framework for the development of olfactory storybooks for young children.

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